

J/ψ Production in Pb–Pb collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV

Ionut-Cristian Arsene for the ALICE Collaboration

Research Division and ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für
Schwerionenforschung, Darmstadt, Germany

E-mail: i.c.arsene@gsi.de

Abstract. We report on the J/ψ production in Pb–Pb collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV recorded with ALICE during the 2010 and 2011 LHC runs. The J/ψ candidates are reconstructed using the e^+e^- and $\mu^+\mu^-$ decay channels at mid- and forward rapidity, respectively. We show the J/ψ nuclear modification factor R_{AA} as a function of centrality, transverse momentum and rapidity. Our results are compared to the lower energy measurements from PHENIX and to model calculations.

1. Introduction

The Quark Gluon Plasma (QGP) is a state of deconfined nuclear matter formed in relativistic heavy ion collisions. One of the promising proposed probes to study such a state is the suppression of heavy quarkonia (bound states of $c\bar{c}$ and $b\bar{b}$ pairs) via Debye screening [1]. Due to their large mass, the pair creation of heavy quarks occurs in the initial partonic stage of the collision, thus enabling them to experience the entire history of the collision. Without any cold nuclear matter (CNM) effect, the total production cross-section of these pairs in nuclear collisions should correspond to the one in nucleon-nucleon collisions scaled with the number of binary nucleon-nucleon collisions (N_{coll}). It is expected that the production probabilities of quarkonium states are affected by the hot and dense QGP which makes them a sensitive tool for its properties. At the lower collision energies from SPS and RHIC, a strong J/ψ suppression is observed. However, the interpretation of these results is still under debate due to insufficient understanding of the CNM effects which break the N_{coll} scaling. It is expected that the measurements in Pb–Pb collisions at LHC energies will shed more light on this subject. Shadowing, the modification of the free nucleon gluon distribution functions, is the dominant contribution to the CNM effects at LHC energies and will be measured in p-Pb collisions.

In these proceedings we report on measurements of the inclusive J/ψ production as a function of centrality, transverse momentum (p_{T}) and rapidity (y) in Pb–Pb collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV recorded using the ALICE setup during the 2010 and 2011 runs. The results are presented using the nuclear modification factor (R_{AA}) which is defined as

$$R_{\text{AA}} = \frac{1}{N_{\text{coll}}} \times \frac{\sigma_{\text{J}/\psi}^{\text{Pb-Pb}}}{\sigma_{\text{J}/\psi}^{\text{pp}}} \quad (1)$$

where $\sigma_{\text{J}/\psi}^{\text{Pb-Pb}}$ and $\sigma_{\text{J}/\psi}^{\text{pp}}$ are the inclusive J/ψ cross-sections in Pb–Pb and pp collisions, respectively. N_{coll} is obtained using Glauber model calculations.

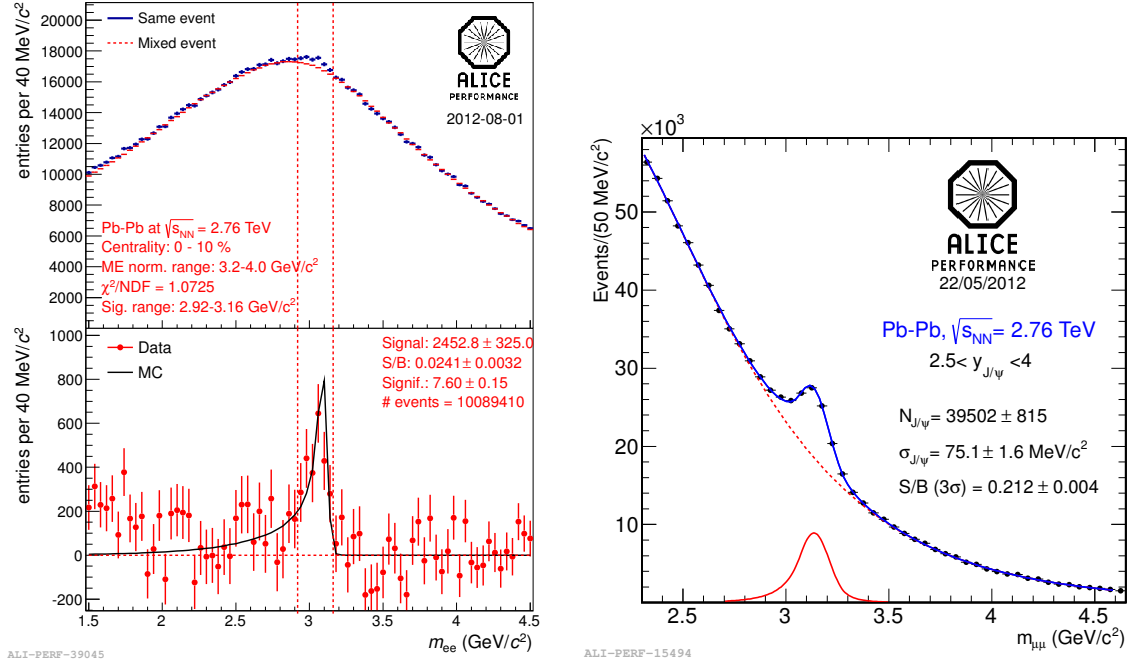


Figure 1. Invariant mass distribution for e^+e^- (left) in central (0-10%) and $\mu^+\mu^-$ (right) pairs in minimum bias Pb-Pb collisions.

2. Experimental setup and data analysis

A detailed description of the ALICE experimental setup is provided in [2]. It consists of several types of tracking and particle identification detectors covering the mid-rapidity region ($|\eta| < 0.9$) and a forward muon spectrometer covering the range $2.5 < \eta < 4.0$. Additional smaller detectors are used for triggering and event characterization. At mid-rapidity, the J/ψ are reconstructed in the di-electron decay channel. The electrons are tracked using the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). Electron identification is done using the specific energy loss in the TPC gas. At forward rapidity, the J/ψ are measured in the di-muon decay channel, with the muons being tracked, using five tracking stations, which are placed behind the hadron absorber. A fast triggering system placed behind an additional iron wall ensures further background rejection and increases the inspected luminosity. The J/ψ coverage at both mid-rapidity and forward rapidity extends down to zero transverse momentum. The present measurements do not allow for a separation between direct and feed-down J/ψ from the decays of higher mass charmonium states or from B mesons, so in the following we always refer to inclusive J/ψ . Detailed descriptions of this analysis are given in [3, 4, 5, 6, 7].

For the di-electron channel, the event sample used for this work consists of 30 million events, the majority of them being centrality-triggered collisions. For the di-muon channel we used 17.7 million di-muon triggered events. The analyzed events correspond to an integrated luminosity of $15\mu b^{-1}$ in the di-electron channel and $70\mu b^{-1}$ in the di-muon channel.

The J/ψ signal is extracted from the invariant mass distribution constructed from opposite-sign (OS) pairs of electron or muon candidates (see Fig.1). The dominant background contribution in the OS invariant mass distribution is coming from uncorrelated pairs. For the di-electron channel, the background is constructed using the event mixing technique. Within the statistical uncertainties a good agreement is found between the background-subtracted distribution and the signal shape as expected from our Monte-Carlo (MC) simulations (bottom-

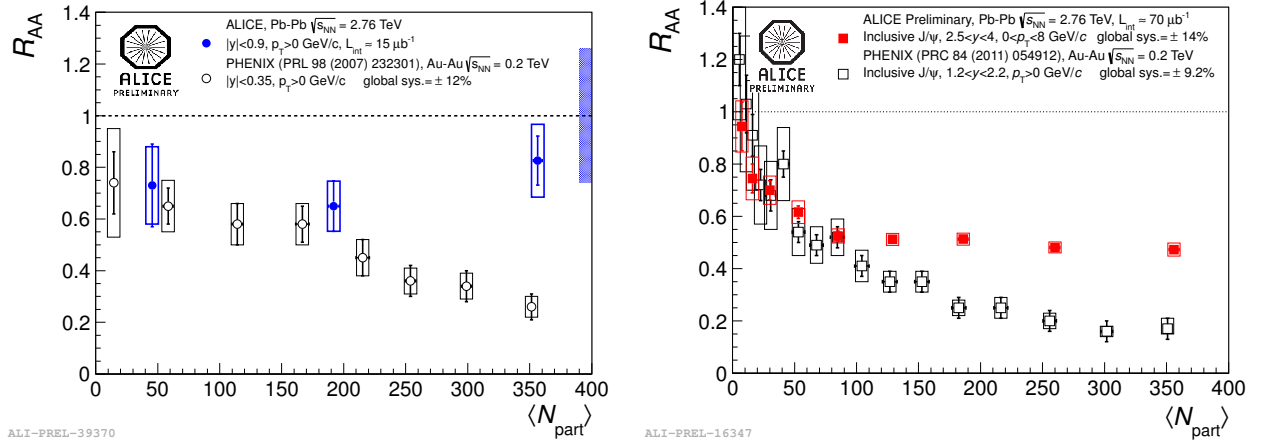


Figure 2. J/ψ nuclear modification factor R_{AA} as a function of the number of participant nucleons at mid-rapidity (left panel) and forward rapidity (right panel) compared with the measurements from PHENIX in Au-Au collisions at $\sqrt{s_{NN}}=200$ GeV.

left panel of Fig.1). The contribution from the correlated e^+e^- continuum surviving the mixed event background subtraction are incorporated in the systematic uncertainties for the signal extraction. Finally, the raw J/ψ signal is obtained from bin counting in the range $2.92 - 3.16$ GeV/ c^2 . In the di-muon channel, thanks to the dedicated trigger system and better signal to background ratio, the raw J/ψ yields could be extracted using two different methods. One method employs fitting of the $\mu^+\mu^-$ distribution with a sum of a modified Crystal Ball (CB2) function and a variable width gaussian for background parameterization (right panel of Fig.1). Alternatively, the mixed event background was subtracted and the remaining distribution was fitted with the sum of a CB2 function for the signal and an exponential function to parameterize the remaining correlated background.

The raw J/ψ signal was corrected for trigger efficiency, acceptance and reconstruction efficiency using simulated Pb-Pb collisions employing the HIJING event generator enriched with primary J/ψ . The transport of the generated particles through the detector is done using GEANT3. Furthermore, in the case of the di-muon decay channel, the efficiencies were calculated by embedding simulated J/ψ into the raw data of real events. Details on the efficiencies and the systematic uncertainties can be found in [5, 6, 7].

3. Results and discussion

The nuclear modification factor is obtained using the J/ψ cross-section in pp collisions (see Eq.1) at $\sqrt{s}=2.76$ TeV measured by ALICE [4]. The systematic uncertainty on the R_{AA} due to the statistical and systematic errors on the pp reference amounts to 26% for the di-electron channel. For the di-muon channel, the corresponding error, which is dominated by the systematic uncertainty, is 9% for the integrated results and 6% for the p_T or y dependent results.

Figure 2 shows our results on the R_{AA} as a function of the number of participant nucleons (N_{part}) around mid-rapidity (left column) and at forward rapidity (right column). At mid-rapidity, the results show no N_{part} dependence within the experimental uncertainties and an R_{AA} value in the most central collisions of $0.83 \pm 0.09(\text{stat.}) \pm 0.26(\text{syst.})$ has been obtained. At forward rapidity, the results indicate a clear J/ψ suppression which is constant with centrality for $N_{part} > 50$. In Figure 2 our results are compared with the ones from PHENIX measured in Au-Au collisions at $\sqrt{s_{NN}}=200$ GeV [8] at mid-rapidity (left) and forward rapidity (right).

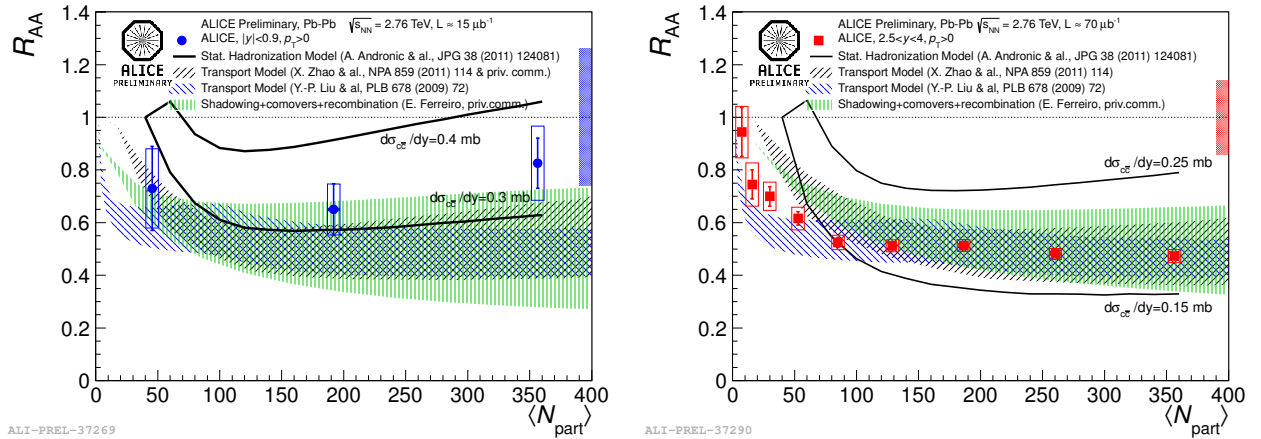


Figure 3. J/ψ nuclear modification factor R_{AA} as a function of the number of participant nucleons at mid-rapidity (left panel) and forward rapidity (right panel) compared with model calculations.

For the most central collisions, the J/ψ R_{AA} is significantly higher at the LHC at both mid- and forward rapidity. The R_{AA} measured by PHENIX shows a strong suppression in central collisions. Whether this observation is compatible with J/ψ suppression beyond the CNM effects, measured in d-Au collisions [10], is still under debate. Phenomenological calculations from [9] suggests that the observed nuclear suppression in Au–Au collisions may be explained solely with the CNM effects, which include nuclear shadowing and the breakup of correlated $c\bar{c}$ pairs in cold nuclear matter. At the LHC, it is expected that the high charm quark density enhances the formation probability of quarkonia during or at the end of the QGP evolution [11, 12]. Our results for central collisions suggest that this effect could have a significant contribution.

Figure 3 shows a comparison of our results with model calculations which take this effect into account. The hashed bands show the results from two transport models [13, 14] and from the comover interaction model [15]. In these models the fraction of J/ψ resulting from (re-)combined $c\bar{c}$ pairs from the medium is at most 50%, the rest being direct J/ψ produced during the hard partonic interactions. The solid lines show the prediction from the statistical hadronization model [16]. This model assumes that no charmonium is formed in the QGP phase and the charm quarks thermalize with the whole system. All the J/ψ and other charmed hadrons are then formed at the chemical freeze-out and their yields can be calculated based on the total charm cross section and the thermal parameters. All of the model calculations have uncertainties due to the unknown inclusive $c\bar{c}$ production cross section and the CNM effects. The CNM effects will be measured in p-Pb collisions scheduled for beginning of 2013.

Figure 4 shows the p_T (left) and the rapidity (right) dependence of the J/ψ R_{AA} . The p_T dependence is shown for both central (0-20%) and peripheral collisions (40-90%) in comparison with calculations from a transport model [13]. The results for central collisions show that R_{AA} is ≈ 0.6 at low p_T and decrease towards higher p_T . For the peripheral events, we observe no or little p_T dependence within the uncertainties. These results are in fair agreement with the model calculations from [13] with the exception of the peripheral collisions where the model seems to overestimate the data at low p_T . The rapidity dependence of R_{AA} for the most central (0-10%) collisions is shown in the right panel of Fig.4. We observe that the R_{AA} grows from forward to mid-rapidity. This behaviour was observed also at RHIC energy in the most central collisions. Although there are more effects which need to be taken into account, these results might suggest that the (re)generation mechanism becomes important at LHC since the

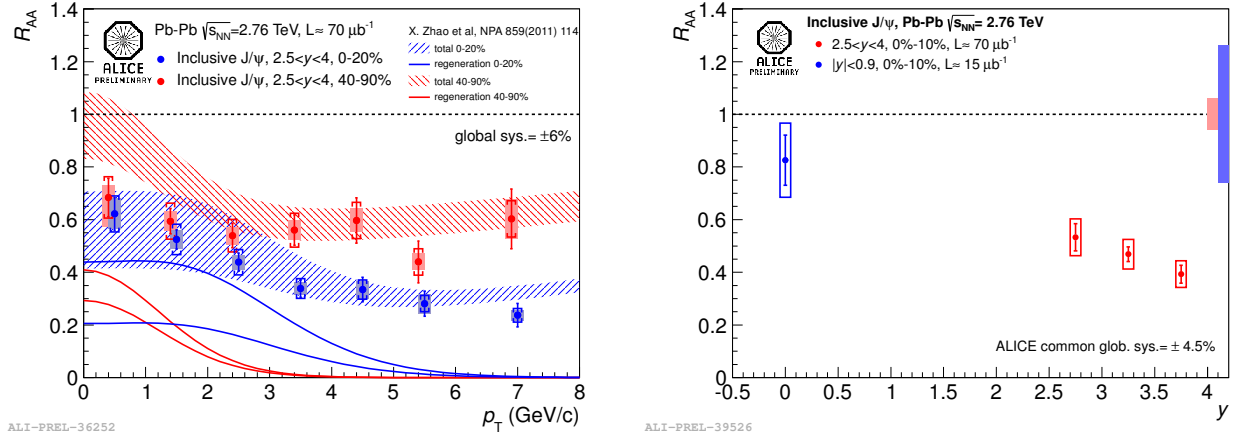


Figure 4. J/ψ nuclear modification factor R_{AA} as a function of transverse momentum at forward rapidities ($2.5 < y < 4$) (left) and as a function of rapidity (right).

charm density is expected to grow from forward to mid-rapidity.

4. Conclusions

To summarize, we reported on the latest ALICE measurements of the inclusive J/ψ nuclear modification factor as a function of centrality, p_T and y in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. In the most central collisions our integrated R_{AA} values are roughly 3 times higher than the results obtained in central Au–Au collisions by PHENIX collaboration. Model calculations which incorporate the (re)generation mechanism are in agreement with the data. Better knowledge of the total charm cross-section and the CNM effects will impose more stringent constraints to models. A comparison of the p_T dependence of the J/ψ R_{AA} in central collisions indicates that the (re)generation mechanism is significant at low transverse momentum. Finally, the J/ψ R_{AA} in central collisions is decreasing with increasing rapidity as was also observed at RHIC.

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